

HIGH INTEGRITY MAGNESIUM AUTOMOTIVE COMPONENTS (HIMAC)

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AMD 601

2009 DOE Merit Review Presentation

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Overview

Timeline

- Project start date: 4/15/2006
- Project end date: 3/31/2010
- Percent complete: 74%

Budget

- Total project funding
 - DOE share \$3 M
 - USAMP share \$3 M
- Funding received in FY08: \$760.7 K
- Funding for FY09: \$800 K
- Funding for FY10: \$400 K

Barriers Addressed

Develop improved high volume manufacturing techniques for shaping (casting, forming, etc.)

- > The four casting processes (Squeeze Cast; LPPM; Ablation and T-Mag) were not developed for magnesium at the start of this project.
- > Thermal processing was available for aluminum components, but not cost effective for magnesium components.
- > Standards and techniques for effective and economic grain refinements were not available or developed for the Mg processes.

Partners

- **OEMs:** Chrysler, Ford, GM
- Suppliers, universities, etc.: 39 (see list - next slide)

Project Participants

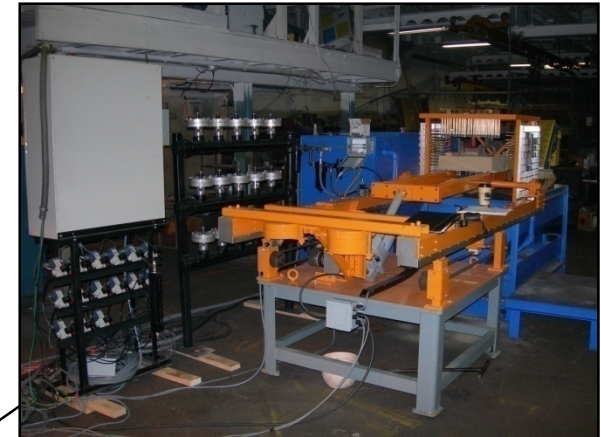
Alotech Ltd. LLC
American Foundry Society
Arizotah Global Enterprises LLC
Buhler Prince Inc.
CANMET
Case Western University
Casting Technologies Company
Chem. Trend
Contech Global
CMI Equipment and Engineering
CMI Novacast Inc.
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Technology
Chrysler Corporation
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Foseco Metallurgical Inc.
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Meridian Lightweight Technologies Inc.
NADCA
Nanjing Welbow Metals Co. LTD
Purdue University
Product Development & Analysis LLC
Quasar International Inc.
University of Alabama
University of Iowa
Worcester Polytechnic University
Westmoreland Mechanical Testing Research

Overview—Casting Processes



Task #1-Squeeze Cast



Task #7-1 Ablation



Task #2-Low Pressure Permanent Mold (LPPM)



Typical Mg Control Arm



Task #7-2 T-Mag

Objectives

The project goals during CY 2008 included:

- Finalize the squeeze and low-pressure casting processes (Task #1 & 2) to deliver high integrity Mg castings by the end of the first quarter CY 2008 for investigation and evaluation
- Build and test the complete electromagnetic pump for controlled molten metal transfer and filling (Task #6)
- Evaluate potential of emerging (new) Mg casting technologies, including the ablation process and T-Mag process for casting of identical Mg control arms
- Integrate the findings of the industrial base and academic R&D into the on-going investigations of the 4 casting processes. This includes:
 - > Thermal treatment (Task #3)
 - > Microstructure control including grain refinement (Task #4)
 - > Computer modeling and properties for control of porosity and hot tear (Task #5)
- Meet all funding and in-kind support activities in accordance with the project's original Statement of Work (SOW)
- Conduct HIMAC project activities in accordance with USAMP's previously published document: *"Magnesium Vision 2020, A North American Automotive Strategic Vision for Magnesium"*, and the American Foundry Society Division 6 publication: *"Magnesium Casting Roadmap"*

Approach

CURRENT STATE

- ☐ High Pressure Die Casting
 - Lack of Consistent Properties and lack of Ductility
- ☐ No process development in magnesium for squeeze casting
- ☐ Limited process development for low pressure casting of magnesium
- ☐ No process and alloy development for ablation
- ☐ Lack of a pump to transfer molten metal in controlled amounts for low pressure casting of magnesium.
- ☐ High Cost of Heat Treatment
- ☐ High cost of Grain Refining
- ☐ Lack of computer modeling of flow and solidification and material properties for modeling

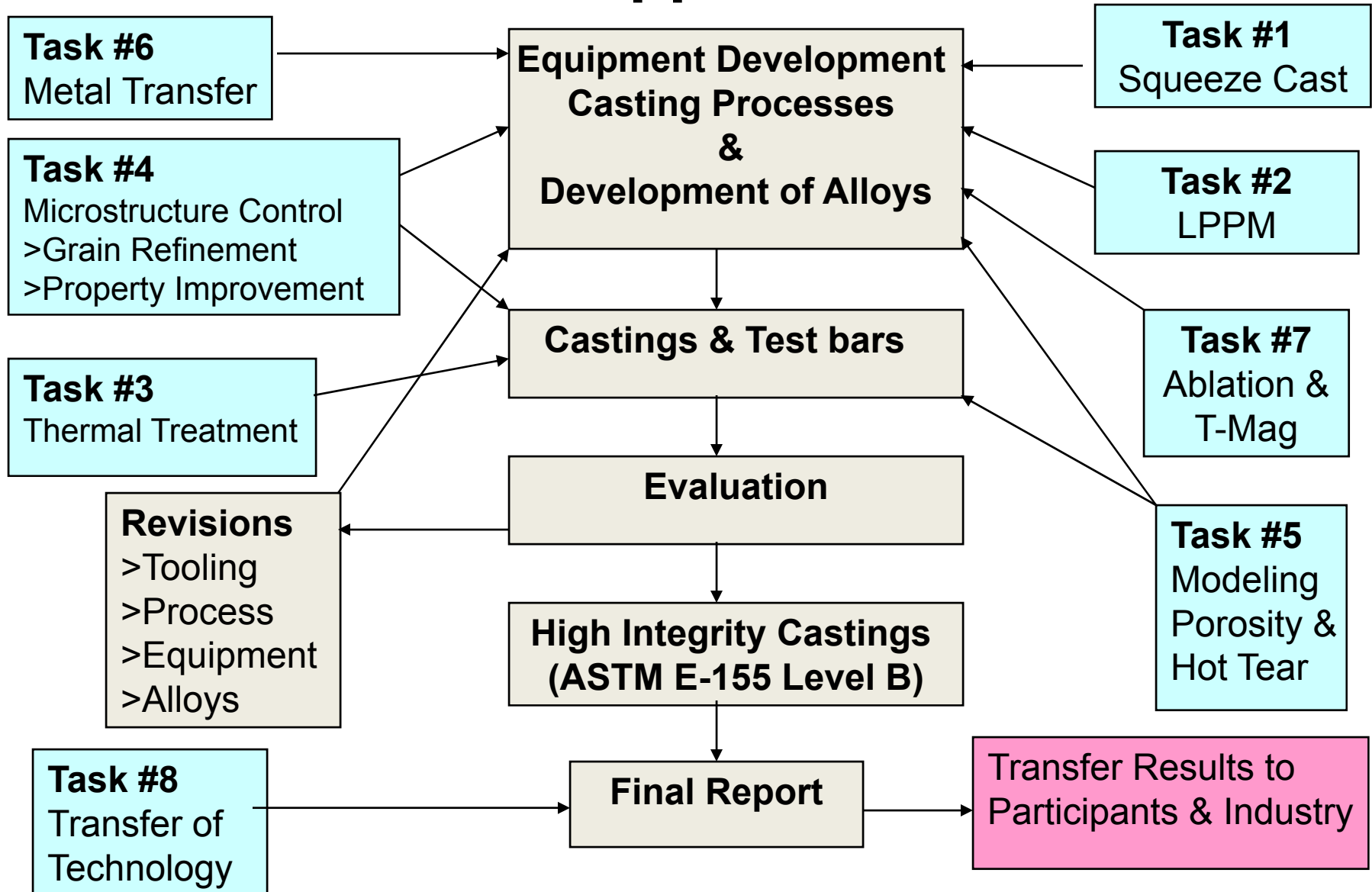
ROADMAP

- ☐ Convert aluminum casting processes to magnesium
 - Squeeze Casting
 - Low Pressure Permanent Mold Casting
 - Lost Foam
- ☐ Develop ablation for use with magnesium
- ☐ Develop a pump for controlled molten transfer of magnesium
- ☐ Develop affordable grain refining techniques for magnesium
- ☐ Develop affordable heat treat cycles for magnesium
- ☐ Develop material properties for computer modeling for flow and solidification

FUTURE STATE

- ☐ Squeeze Casting process to produce cost effective magnesium components
- ☐ Low Pressure Casting process to produce cost effective magnesium components
- ☐ Ablation Casting process to produce cost effective magnesium components
- ☐ Cost Effective magnesium grain refiners
- ☐ Cost effective heat treat cycles
- ☐ Computer models to effectively predict flow and solidification for all of the magnesium casting processes.
- ☐ Recycling methods for all magnesium alloys
- ☐ An environmentally favorable cover gas

Approach

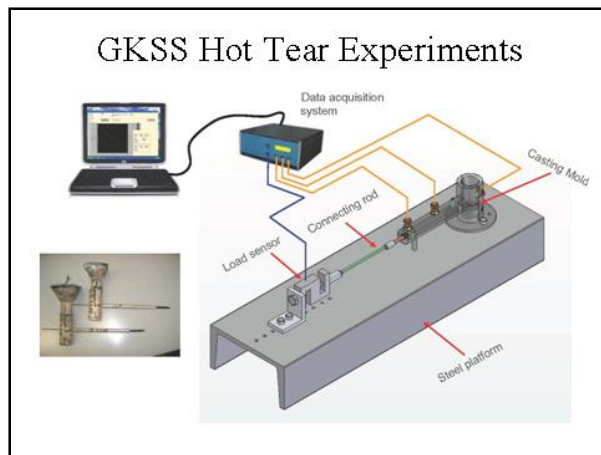
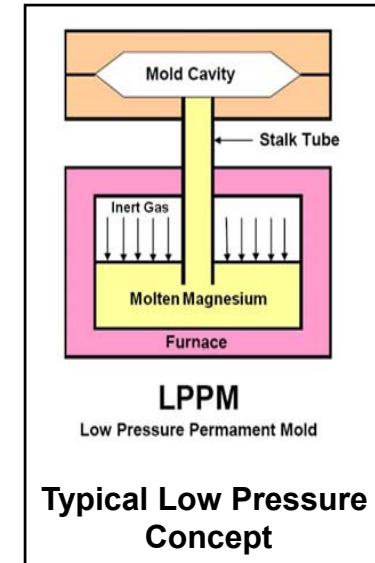


Milestones

- Meridian has developed the Squeeze Casting process to produce castings from AM60 and AZ91 alloys
- CMI Equipment and Engineering (CMI E & E) has: provided the technology to develop the LPPM Casting Process for Task #2; built the equipment and developed the process; produced castings of acceptable levels with good appearance, minimum porosity and hot tears from AM60 and AZ91 alloys
- Thermal Treatment evaluation has begun
- Four Universities and CANMET have studied grain refinement in magnesium castings including: types; methods of implementation; quantities; size of particles; cost and mechanical properties and results with respect to the reduction of porosity and casting ability for AM60 and AZ91 alloys
- Model to predict porosity, hot tears and properties was developed by U. of Iowa
- Selection of Ablation Casting mold aggregate; AZ91 alloy selected; inhibitor and die-build have all been completed.

Accomplishments

- Three selected aluminum casting processes (LPPM; Squeeze Cast; Ablation) have been developed for magnesium alloys and control arms have been successfully cast
- Castings have been investigated to verify initial mechanical and microstructure properties. and will become the benchmark for future evaluation of the final castings.
- Cost expenditures match original budget numbers; In-Kind support exceeds forecast.
- Modeling techniques have been identified to minimize hot tear and porosity and implemented for the different types of Mg alloys and casting processes.



Hot Tear Model Yield Function

$$Y(\epsilon_s^{eqp}, \dot{\epsilon}_s^{eqp}, T) = \sigma_0(T) \left(1 + \frac{\epsilon_s^{eqp}}{\epsilon_0^{eqp}(T)} \right)^{n(T)} \left(1 + \frac{\dot{\epsilon}_s^{eqp}}{\dot{\epsilon}_0^{eqp}(T)} \right)^{m(T)}$$

• Nomenclature

- Elastic Modulus (E)
- Poisson's Ratio (ν)
- Initial Tensile Yield Strength (σ_0)
- Hardening Exponent (n)
- Shear Plastic Strain (ϵ_s^{eqp})
- Reference Shear Plastic Strain ($\epsilon_0^{eqp} = \frac{\sigma_0}{n \cdot E}$)
- Shear Strain Rate ($\dot{\epsilon}_s^{eqp}$)
- Strain Rate Sensitivity Exponent (m)
- Reference Shear Strain Rate ($\dot{\epsilon}_0^{eqp}$)

Accomplishments

- New R & D laboratory procedures have been developed using high-intensity ultrasonic vibration for improved dispersion of grain refining nanoparticles in molten metal. Laboratory use of ultrasonic vibration has been tested to positively influence alloy solidification behavior.
- The HIMAC casting processes developed to date using AZ91 and AM60 Mg alloys has proven the feasibility of casting Mg.
- Initial castings from two processes have been thermally treated with the advanced fluidized bed system, significantly reducing cycle time.
 - > Rapid microstructural modification
 - > Reduced heat treatment time from a typical 8 hours to 2 hours.

Thermal Treatment Facilities

Fluidized Bed Heating of the Control Arm



Batch fluidized bed HT system

Work holder and Control Arms



Accomplishments

Weight reductions have been identified from Squeeze Cast Process using AM60 Mg Alloy. Results identified to date are as follows:

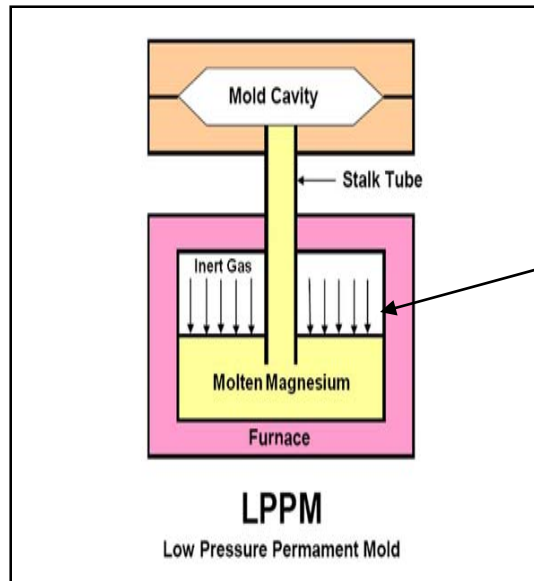
- Steel Control Arm Assembly: 3.095 kg
- Steel Control Arm Stamping: 2.255
- Meridian Mg Control Arm Machined: 1.601
- **Mass Savings 0.654 kg**
- **Mass Savings Assembled 21%**
- **Mass Savings Component 29%**

Future Work

- Tooling and process parameters for the four new magnesium casting processes will continue to be improved, with the implementation of the metal grain refinement and modeling techniques to improve castability for production of high integrity components with reduced porosity, oxides and the elimination of hot tears in the Mg Control Arm.
- Following the production of 100 High Integrity Castings from the LPPM Cell, the low pressure system that delivers molten metal to the mold cavity will be replaced with an electromagnetic pump. Additional castings will be made by this revised process, and microstructure and mechanical properties will be compared to all other castings produced by the four processes.



LPPM Casting Cell



Electromagnetic Pump
will be submerged into the
furnace and molten metal
transferred into the mold cavity.

Future Work

- 100 Mg Control Arms will be cast by each process. Representative castings will be selected from each of the four process to be evaluated using: x-ray inspection; static and fatigue testing for durability; and mechanical properties will be compared to micro-porosity results.
 - > The fourth process (i.e., “T-Mag”) will start casting the control arm during the middle of CY 2009
- Cost studies will be performed that will compare the results of the four casting processes.
- Compile information for the Final Report:
- Continue the Technical Transfer of Project Information through publications and presentations
- Assure that the SOW Tasks are completed on time.
- Continue to improve the potential weight savings/Mg control arm component versus steel stamping component, with process and tooling improvements.
- OEMs project team members expressed interest in evaluating high strength Mg alloys to improve mechanical properties of the Mg Control Arm. This would require additional funding and extension of the HIMAC project.

Summary

- The HIMAC project has continued the Mg project type work that originally started with the *Structural Cast Magnesium Development (SCMD)* Project, and it will provide technical support to the Magnesium Front End Research and Development Project (AMD 604).
- Three of the four focused casting processes have provided initial castings for evaluation as defined in the project SOW. T-Mag (the fourth process) will soon follow, as they had a late start of 18 months. All processes will continue to be improved throughout CY 2009.
- Continue to resolve technical barriers (e.g., porosity, hot tears, grain refinement) that were originally defined in the SOW.
- Six different universities are actively involved in the HIMAC Project, including students from undergraduate to PhD levels.
- The core HIMAC Project Team (industry; academia; CANMET and automotive support teams) have successfully worked together on two previous USAMP projects, and have always finished the projects on time, within budget, and provided results that can be used by OEMs and the Magnesium industry.
- Cost expenditures match the original budget numbers and in-kind support meets or exceeds forecasted numbers.
- To date, potential weight savings of Mg control arm component versus steel stamping component is approximately 29%.